A Biomechanical Analysis of Capsular Plication Versus Anchor Repair of the Shoulder: Can the Labrum Be Used as a Suture Anchor?

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Purpose: To determine the biomechanical strength properties of suture capsulolabral plication to an intact labrum versus glenoid bone anchor fixation. **Methods:** Fourteen paired fresh frozen shoulders with intact glenoid labrum and mean age of 43.3 ± 11.1 were randomized to capsular plication in the anteroinferior and posteroinferior quadrants using either two suture-anchor fixation versus suture fixation to an intact labrum. The construct was then preconditioned at 10 N for 10 cycles (1 Hz), and then loaded to failure at 3 mm per minute. **Results:** There was no statistical difference in ultimate load to failure between the suture anchor (304.3 ± 92.8 N) and the intact labrum (285.6 ± 66.7 N) groups. The suture anchor group demonstrated significantly less mean displacement (2.15 ± 1.1 mm) than suture plication (3.43 ± 1.38 mm; $P = .007$) at failure. There were no statistical differences of labrum strength and stiffness between the anteroinferior and posteroinferior quadrants. **Conclusions:** An intact labrum provides similar fixation strength to a glenoid anchor; however, the labrum displacement was higher with plication alone. There were no strength differences between the anteroinferior and posteroinferior labrum. However, displacement of up to 1.5 mm may be expected without the use of glenoid anchors. **Clinical Relevance:** The intact posteroinferior or anteroinferior labrum provides similar fixation strength to a glenoid anchor; however, the labrum displacement is higher versus plication alone.
Key Words: Labrum—Plication—Shoulder capsule—Shoulder instability—Suture anchors.

Arthroscopic techniques have become an accepted method of performing shoulder stabilization procedures. In most cases of traumatic instability, a labral tear is present, which requires repair to the glenoid rim using suture anchors. However, in certain cases, capsular plication of the posteroinferior or anteroinferior quadrants is recommended either to supplement labral repair with capsular laxity, or in cases with instability and no appreciable labral tear.[1] When used, capsular plication is performed to reduce laxity in either the anterior or posterior band of the inferior glenohumeral ligament (IGHL) and capsular structures.[2-10]

When performing a capsular plication, the goal is to create a fold in the capsular tissue to remove redundancy. Capsulolabral repair fixation is achieved by utilizing either a glenoid bony anchor or to the circumferential fibers of the intact labrum to hold the plication suture in place. The biomechanical properties of an intact labrum and whether the labrum can reliably be utilized as a glenoid anchor substitute have not been fully investigated.

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The purpose of this study was to determine the biomechanical properties of suture plication performed using a glenoid bone anchor versus plication repair to an intact labrum. The biomechanical differences of labrum strength in both the anteroinferior and posteroinferior quadrants of the shoulder will also be investigated. Our null hypothesis was that there would be no biomechanical differences between suture anchor glenoid capsulolabral fixation and fixation to an intact labrum alone.

METHODS

A total of 14 matched (7 right, 7 left) fresh-frozen cadaveric shoulders with a mean age of 43.3 ± 11.1 years were thawed and all soft tissue dissected except for the glenohumeral capsule and labrum. Once all soft tissues were dissected, the humeral head was freed from the capsule at its most lateral humeral insertion point to preserve as much capsule as possible. All glenoids were inspected and excluded if there were any significant degenerative changes or if there was any absent labral tissue, and, in young cadaveric specimens, had to have a visually normal-appearing glenoid labrum. In addition, specimens were excluded if the inferior half of the glenoid labrum had any labral damage, such as cracks, splitting, partial displacement, fissures, or any incompetence of the labral tissue upon probing and visual inspection. All glenoids then underwent dual-energy x-ray absorptiometry (DEXA) bone density testing with a bone densitometer (GE-Lunar Prodigy Advance System, enCore software v 11.2, Madison, WI), set to 76.0 kV, 0.150 mA for small body parts. A consistent 2-mm^2 portion of superior center of each glenoid specimen was measured.

Once dissected, the scapula was then potted. Specimens were then randomized to receive either a suture plication (labrum only, no anchors) or an anchor repair utilizing metal suture anchors in either the anteroinferior (AI) or posteroinferior (PI) quadrant of the glenoid. The quadrants were defined as the inferior half of the glenoid from 3 o'clock to 9 o'clock, with the separation between the AI and PI quadrants at the 6 o'clock position. The contralateral shoulder was then repaired using a reversal of the matched repair pattern. For example, in one matched specimen, anchors were used in the anterior inferior quadrant and the labrum alone was used for fixation in the posterior inferior quadrant. The order was then reversed for the matched contralateral limb. For example, a left shoulder would have anchor repair for AI, labrum plication for PI; and the matched contralateral right shoulder would have labrum plication for AI and anchor repair for PI.

For all groups, a spectrum (Linvatec, Largo, FL) with No. 1 polydioxanone (PDS; Ethicon, Somerville, NJ) was utilized for suture passage and a No. 2 Fiberwire suture (Arthrex, Naples, FL) was used to perform the repair. In an effort to maintain standardization and comparability, a digital caliper was used in all specimens to measure a 1-cm capsular plication of either the AI or PI quadrants, at an identical sagittal angle to the glenoid. The suture passing device entered the capsule 1 cm lateral to the labral edge, and care was taken to ensure that the suture passed through the chondrolabral junction—the margin between the glenoid and labral tissue—to ensure that all circumferential fibers of labral tissue were captured. The first and most inferior suture was placed through the glenoid labrum at a position 6 mm superior to the 6 o'clock position (either anterior or posterior, depending on group). A second suture was then added to the labral repair at a point 12 mm superior to the 6 o'clock position. Each No. 1 PDS was shuttled and exchanged for the No. 2 Fiberwire suture. Before tying the two repair limbs of No. 2 suture, a third No. 2 Fiberwire suture was passed within the repair loops and anchored to the biomechanical testing apparatus (Fig 1). The repair loops were then tied using a total of 6 nonsliding arthroscopic alternating half-hitch knots with a knot pusher. Thus, the free No. 2 Fiberwire stitch was cinched down by the two repair stitches and would be utilized as the conduit for biomechanical testing. A set distance of 6 mm between suture plications was maintained in all specimens.

For those specimens randomized to suture anchor repair, a 3.5-mm metal corkscrew anchor (Arthrex, Naples, FL) was placed in the glenoid bone at the chondrolabral junction. Two anchors were placed in the same location as the plication sutures described above (at 6 mm and 12 mm superior to the 6 o'clock position). Anchors were inserted at a 40° angle to the glenoid face[11-14]; the anchor suture eyelet was oriented so that the suture limbs were in line for direct passage into the labrum without crossover. Again, the Spectrum suture passing device was used to shuttle one limb of the anchor suture through the intact labrum and capsule as described above, utilizing a No. 1 PDS suture. A free No. 2 Fiberwire suture was placed into the suture loops before tying the knots. As in the capsulolabral repair specimens, the free No. 2 Fiberwire was long enough and free at each end to be loaded into the clamp of an MTS (MTS Systems

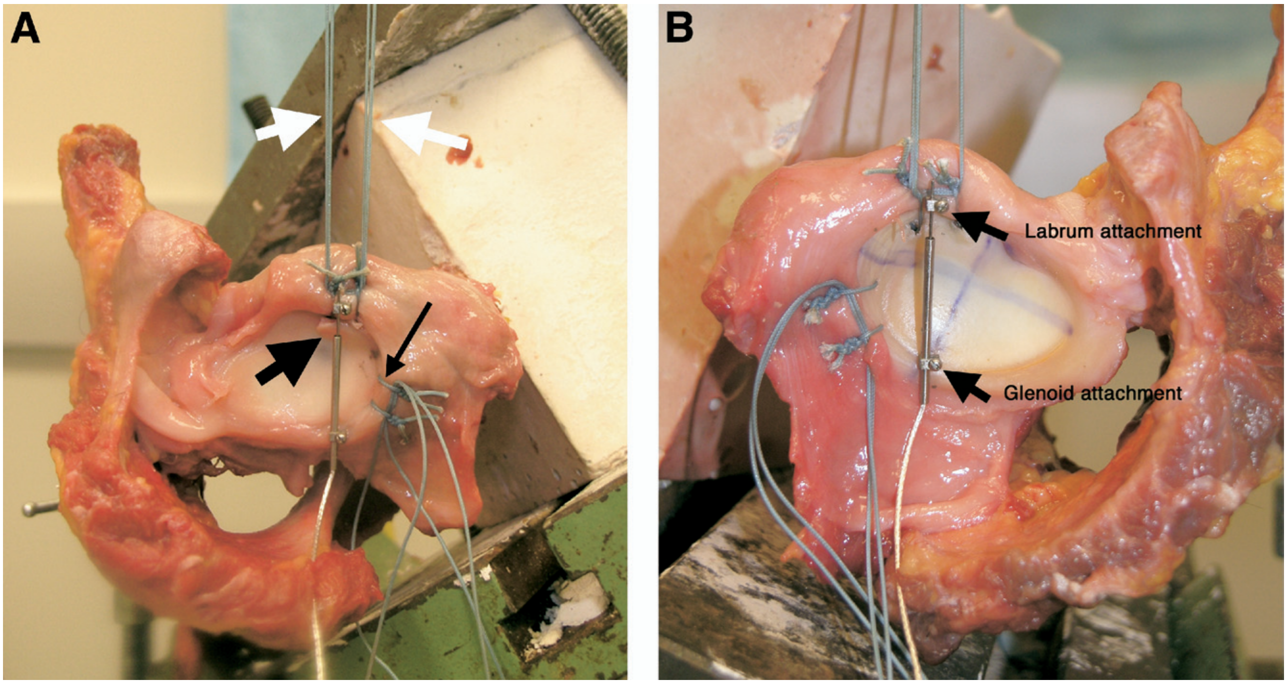

FIGURE 1. (A) Specimen setup on the MTS machine. The anteroinferior glenoid labrum is being tested in a "worst case scenario" vector, in the anteroinferior direction. The anteroinferior labrum is repaired with 2 suture anchors *(large black arrow)*, whereas the posteroinferior labrum is repaired to the intact labrum *(thin black arrow)*. Each quadrant is connected to the MTS machine by 2 No. 2 Fiberwire (Arthrex, Naples, FL) through the loops of the labral repairs *(two white arrows)*. (B) The differential variable reluctance transducer (DVRT; MicroStrain, Burlington, VT) is shown. *Two black arrows* show the attachment points. In the *lower arrow*, the DVRT is firmly attached to the glenoid bone; in the *upper arrow*, the DVRT is attached to the glenoid labrum. Displacement is measured with the DVRT as the labrum is loaded.

Corporation, Eden Prairie, MN) machine for biomechanical testing.

A "worst case scenario" vector was established using a multiaxial clamp to hold the scapula. In this way, a direct vector could be created between the plication sutures or anchors and the direction of pull. A differential variable reluctance transducer (DVRT; MicroStrain, Burlington, VT) was utilized to measure displacement from the fixed glenoid. It was placed such that 1 DVRT pin (attached to the transducer) was in the glenoid close to the labral edge, and the other pin (attached to the core) was in the lateral labrum edge. The DVRT formed a moveable "bridge" at the repair site, which served to measure total displacement from 2 fixed points (the glenoid and lateral labral edge). The DVRT displacement was then recorded to measure the overall displacement of the labrum (0.01 mm accuracy, measurements taken to 0.1 mm). Load to failure was recorded on a force-displacement curve as measured by the MTS machine. Once the DVRT and MTS machine were attached, the following sequence was utilized based on pilot data:

1. Preconditioning at 10 cycles, 1 Hz, 0 to 10 N
2. Reset the translation of the device and zero out translation, maintaining 10 N preload
3. Pull to failure load at 3 mm per minute
4. Record failure mode grossly (suture rip out, labrum failure, bony failure, etc.)

The pull to failure at 3 mm per minute was chosen based upon pilot data where we found that higher rates of loading (7 to 20 mm/minute) resulted in labrum failure by suture saw-through, which was not found at the lower rates of loading. With 14 specimens, the study had 80% power to detect a difference in means between the anchor and suture only groups with the given number of paired specimens. The differences between the two different repair groups were compared with rank-sum tests, with the level of significance set at $P < .05$.

RESULTS

There was no difference in mean bone mineral density of the shoulder glenoid specimens. The ulti-

Table 1. *Peak Load and Strain at Failure of Construct*

	Capsulolabral Suture Plications to Labrum		Anchor Repairs		Anchor v Suture (Peak Load) *P* Value
	Peak load (N ± SD)	Strain (N/mm ± SD)	Peak load (N ± SD)	Strain (N/mm ± SD)	
Combined AI and PI (overall mean)	285.6 ± 66.7	18.6 ± 4.1	304.3 ± 92.8	20.7 ± 7.9	.290
AI	295.3 ± 82.6	19.1 ± 4.7	298.9 ± 117.9	21.6 ± 10.7	.660
PI	275.8 ± 50.9	18.0 ± 3.7	309.7 ± 68.6	19.7 ± 4.2	.259

Abbreviations: AI, anteroinferior; N, Newtons; PI, posteroinferior; SD, standard deviation.
NOTE. There was no difference in AI v PI peak load for capsulolabral plications ($P = .449$). There was no difference in AI v PI peak load for anchor repairs ($P = .622$).

mate load to failure for the suture anchor group (304.3 ± 92.8 N) was not statistically different from the ultimate failure strength of the intact labrum repair (285.6 ± 66.7 N; $P > .29$; Table 1). The AI and PI quadrants of the shoulder showed similar labral biomechanical strength properties. In 23 of 28 specimens, the failures occurred at the arthroscopic knot (suture failure at the knot), 4 of 28 at the glenoid–labrum interface, and only 1 of 28 with anchor pullout. In the anchor group, 1 failure was through anchor pullout (13 by suture knot failure); in the suture repair group, 4 failed because of labral detachment (10 failed because of knot failure).

The mean displacement at failure was statistically greater for the suture group (3.4 ± 1.4 mm) than for the anchor group (2.2 ± 1.1 mm; $P = .007$). This represented a mean difference of 1.28 mm between the suture and anchor groups, with a difference of 1.6 mm in the AI quadrant and 0.9 mm in the PI quadrant (Table 2). All of the displacement occurred at the chondrolabral junction and not at the suture–suture testing interface. When separated into the two inferior quadrants, the AI and PI anchor fixation demonstrated statistically less displacement than with suture fixation. There were no statistical differences between the overall displacement at failure in either the AI versus the PI suture or the AI and PI anchor constructs (Table 2). There were no statistical differences between stiffness for the anchor versus suture repairs, and also no difference for the two different quadrants (AI strain versus PI stiffness).

DISCUSSION

The principal finding of our study indicates that the intact labrum provides equivalent strength of fixation to that of a glenoid anchor in the AI and PI quadrants. The overall peak load at failure of the glenoid labrum as a stand-alone fixation construct is nearly 300 N. This is in agreement with others[15-19] who have described glenoid labrum failure from 236 to 500, although traditional Bankart repair with 2 sutures has been shown to fail as low as 122.1 N.[16,17,20] Others have shown that after Bankart repair utilizing various glenoid anchors, failure falls between 342 and 983 N.[21] We found that only 4 of 14 suture repair specimens failed at the glenoid anchor. All of the anchor repairs and 4 of the suture repairs failed at the site of the arthroscopic knot, without causing any damage to the glenoid–labrum interface.

All-arthroscopic techniques have become an accepted method of performing shoulder stabilization in cases where the labrum is still well-attached to the glenoid. The surgical technique of suture plication and repair without anchors has been advocated. PI capsular plication has also been described in conjunction with anchor repair of an AI Bankart lesion for those with excessive anterior instability or in certain patient populations (athletes in contact sports).[22] Methods for plication have been described using both suture anchor fixation and the intact labrum alone as a form of

Table 2. *Displacement at Failure of Construct*

	Suture (Displacement, mm ± SD)	Anchor (Displacement, mm ± SD)	*P* Value
Combined AI and PI (overall mean)	3.43 ± 1.11	2.15 ± 1.38	.007*
AI	3.85 ± 1.61	2.24 ± 1.31	.029*
PI	3.01 ± 1.07	2.07 ± 0.99	.05*

Abbreviations: AI, anteroinferior; PI, posteroinferior; SD, standard deviation.
*$P < .05$.

anchor to the glenoid rim. However, there is concern about the ability of the intact labrum to provide adequate fixation strength. We found no differences in strength between the AI and PI labrum versus anchor repair; however, there was an increase of up to 1.5 mm of displacement at the chondrolabral junction in the capsulolabral repair group.

We found no differences in either the AI or PI labrum strength, suggesting that each area may provide a stable repair construct if intact. Others have found that the failure strength of tissues that attach to the labrum is higher than that of what we found for the labrum–glenoid interface. For example, Stefko et al.[23] found that when the IGHL was loaded physiologically, the average load to capsular failure was over 700 N, and it failed at the capsular insertion site, although others have described this value to be much higher.[5,9,19] McMahon[4,5] found that the anterior band of the inferior glenohumeral ligament underwent a small amount of elongation when tested to failure, and most specimens failed at the glenoid–labrum interface at a mean of 353 N. Hara et al.[15] found that glenoid–labrum interface was consistently ruptured close to the hyaline articular cartilage in a test of the strength of 5-mm sections of the glenoid–capsule complex. They also found that the weakest portion of the glenoid–labrum complex was at the AI area of the glenoid, near the 4 o'clock position. They also stated that the microscopic evaluation of the glenoid showed a uniform density and direction of collagen fibers in the different areas of the glenoid[15]; however, it has been shown that the inferior portions of the glenoid are better attached than the superior quadrants.[24] Glenoid bone cortical thickness may also play a role in anchor pullout, because it has been shown to decrease uniformly from superior to inferior.[25]

Our experimental setup was designed to test the holding strength of the intact glenoid labrum and whether a plication using the glenoid labrum alone as an anchor is an adequate substitute for glenoid suture anchors. The vast majority of our 28 specimens failed at the arthroscopic knots. As we were just investigating the strength of the labrum in a clinically applicable setting, the capsular properties were not included in the study. Thus, there was not a problem with sutures cutting through the capsular tissue, as has been previously described as a failure point in glenoid repair studies.[16] The failure of the arthroscopic knots is consistent with studies that have demonstrated a failure of between 80 and 240 N[26-29] for reliable arthroscopic sliding knots and surgeon's knots. Thus, our study did not clearly establish the overall strength of the intact glenoid labrum; rather, we chose to test a clinically applicable scenario of plication sutures with knots that withstood nearly 300 N of force. This finding has direct clinical relevance in that it would suggest that no anchor is required when performing capsular plication for ligamentous laxity in an area with an intact and normal appearing labrum. It is unlikely that the strength of fixation to the labrum alone would remain the same as using a suture anchor when the labrum has visual damage, such as fraying, splitting, or evidence of previous displacement with subsequent healing in situ. If there is any concern on behalf of the surgeon that the labrum has been damaged, anchor fixation to bone is likely to provide the best fixation strength.

Our displacement data demonstrated that the suture capsulolabral plications fared less well than anchor displacement, with a mean difference of approximately 1.3 mm. Although our stiffness was not statistically different (load over displacement), displacement will be variable, and in our case, the anchor demonstrated less displacement, while plication had more displacement, even though the slope (stiffness) was relatively the same.

Burkhart et al.[30] defined a clinical failure of arthroscopic knots of around 3 mm. Whether the 1.3 mm displacement difference is clinically important, much less statistically different, is difficult to determine. However, labrum insufficiency has been described as a cause of failure in revision shoulder stabilization cases, and perhaps the presence of labral fissures and displacement up to 1 to 2 mm may compromise overall repair integrity.[31]

We feel that the clinical application of this study pertains to performing a capsular repair to a normal appearing intact labrum in the setting of shoulder instability. Most often, this is performed in the PI aspect of the glenoid in the presence of a concomitant anterior labral repair, or in cases of shoulder instability without labral tears caused by excessive capsular laxity. Our study has demonstrated that the labrum can, in fact, be predictably relied upon for sufficient strength comparable to the overall strength of a bony suture anchor. Although none of our specimens had evidence of a labral crack or fissure ("Kim lesion"),[32] we feel that it is important that the labrum be thoroughly evaluated to rule out any evidence of detachment or structural weakness caused by damaged labral tissue if suture plication is to be performed without suture anchors.

There are several limitations to this study. First, it represents a time zero in vitro analysis. The method of healing which occurs between capsular tissues after capsular plication is poorly understood. Furthermore, the minimal fixation strength required to tolerate an early passive range of motion rehabilitation program following arthroscopic stabilization is currently unknown. However, clinical results have demonstrated successful outcomes following stabilization using arthroscopic capsular plication with both suture anchors and plication suture alone. This study would suggest that both techniques might be used to achieve adequate fixation to provide initial stability to allow for biologic healing. Secondly, the cadavers used in this study were presumably normal specimens with no instability history. In the case of recurrent instability with capsular laxity, although the labrum appears normal macroscopically, the increased translation that occurs may result in decreased labral fixation strength. Degeneration and decreased blood supply to the glenoid labrum has been described with age[33,34]; therefore, we utilized strict cadaveric inclusion criteria, such that the mean cadaver age was 43.3 ± 11.1 years to minimize the presence of labral degenerative problems or tears that may compromise fixation techniques.

CONCLUSIONS

When performing a capsulolabral plication, an intact labrum provides similar fixation strength to a glenoid anchor; however, the labrum displacement was higher with plication alone. There were no strength differences between the AI and PI labrum. Displacement of up to 1.5 mm may be expected without the use of glenoid anchors. If there is any concern regarding labral integrity, the use of suture anchors is recommended.

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